

# Multi-Decadal Nitrogen Dioxide and Derived Products from Satellites (MINDS) Datasets Released by NASA GES DISC and Their Applications for Air Quality

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Peter Leonard from MINDS Project



# Multi-Decadal Nitrogen Dioxide and Derived Products from Satellites (MINDS)

- A NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) Project
- Goal: To develop long-term (1995 to present) NO<sub>2</sub> global data records by adapting a consistent retrieval algorithm to multiple instrument measurements
- Multiple instruments:
  1. Global Ozone Monitoring Experiment (GOME, 1995-2003) onboard the second European Remote Sensing satellite (ERS-2)
  2. GOME-2 on the Meteorological Operational satellites (MetOp-A and MetOp-B, 2006 - )
  3. Ozone Monitoring Instrument (OMI, 2004 - ) onboard the Aura satellite
  4. TROPOspheric Monitoring Instrument (TROPOMI, 2017 - ) onboard the Copernicus Sentinel-5 Precursor (S5P)
  5. Scanning Imaging Spectrometer for Atmospheric Cartography (SCIAMACHY, 2002-2012) onboard the ENVIRONMENTAL SATELLITE (ENVISAT)



# Challenges and Approach

- Challenges

1. Differences in instrument & measurement characteristics
2. Differences in retrieval algorithms & inputs, affecting data accuracy and inter-satellite data consistency

- Approach

Apply coupled surface reflectivity-cloud-NO<sub>2</sub> algorithms for all sensors and enhance the quality of auxiliary data, including model-derived *a priori* information

(Courtesy of Lok Lamsal et al., 2021 AGU Fall Meeting)

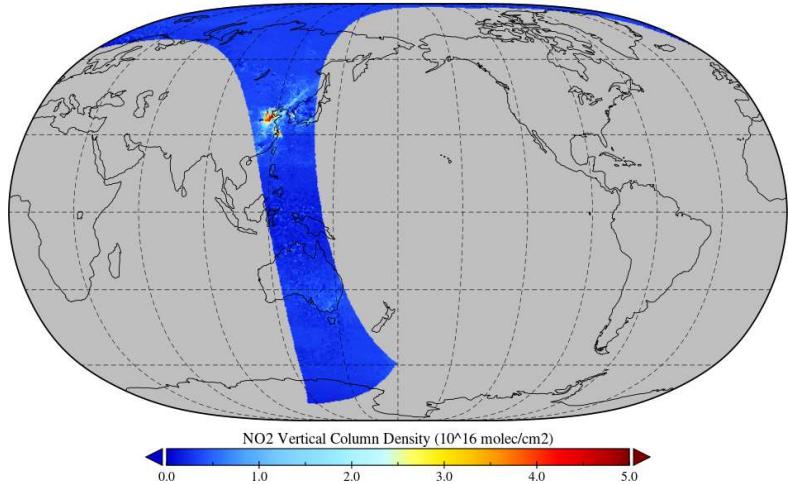


# Published MINDS V1.1 Products

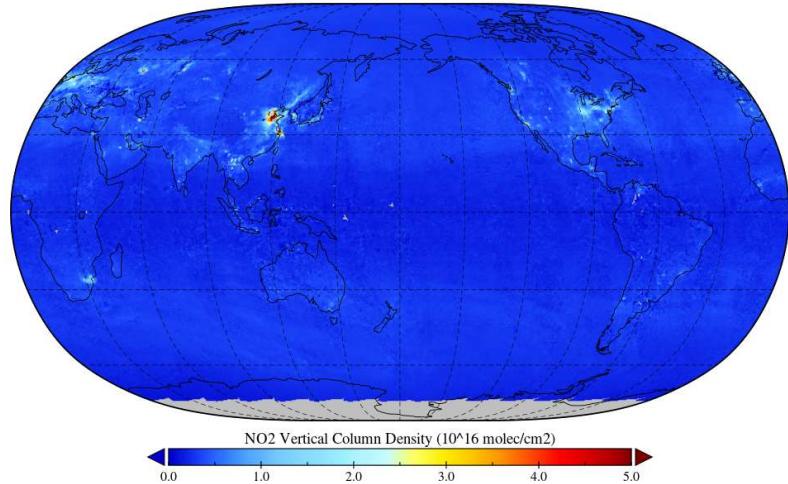
Product	Spatial Resolution	Short Name	Temporal Coverage	DOI
OMI/Aura NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath	13 km x 24 km	OMI_MINDS_NO2	2004 -	10.5067/MEASURES/MINDS/DATA204
OMI/Aura NO2 Tropospheric, Stratospheric and Total Columns MINDS Daily L2 Global Gridded	0.25 degree x 0.25 degree	OMI_MINDS_NO2G	2004 -	10.5067/MEASURES/MINDS/DATA214
OMI/Aura NO2 Tropospheric, Stratospheric and Total Columns MINDS Daily L3 Global Gridded	0.25 degree x 0.25 degree	OMI_MINDS_NO2d	2004 -	10.5067/MEASURES/MINDS/DATA304
TROPOMI/S5P NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath	5.5 km x 3.5 km	TROPOMI_MINDS_NO2	2018 -	10.5067/MEASURES/MINDS/DATA203
GOME/ERS-2 NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath	40 km x 320 km	GOME_MINDS_NO2	1995 - 2003	10.5067/MEASURES/MINDS/DATA202

# MINDS Data Products Sample Images

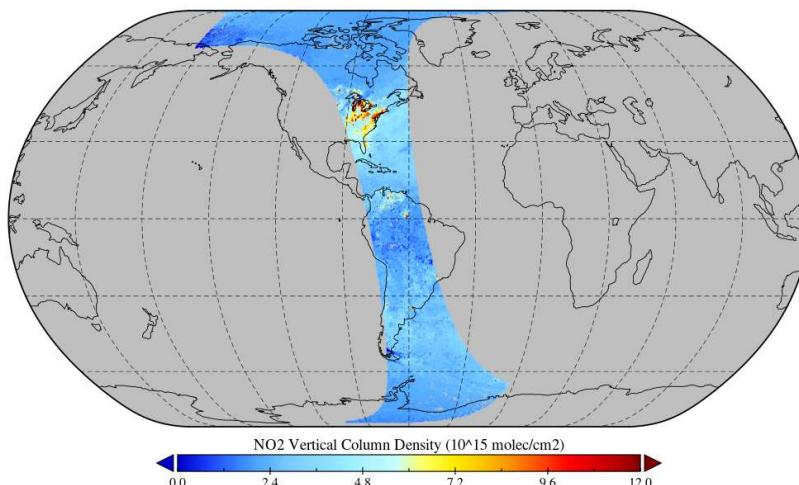
OMI\_MINDS\_NO2 NO2 Total Column Amount for 2005-04-12 (Orbit 3945)



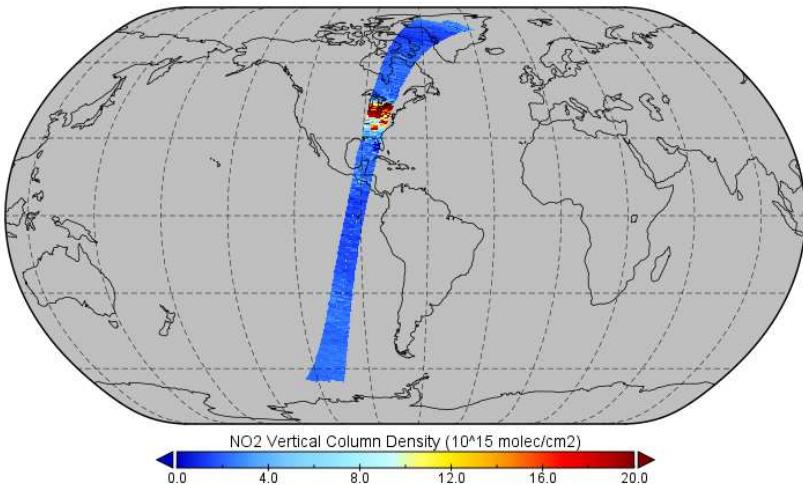
OMI\_MINDS\_NO2d NO2 Total Column Amount for 2005-04-12



TROPOMI\_MINDS\_NO2 NO2 Total Column Amount for 2019-03-27 (Orbit 07524)



GOME\_MINDS\_NO2 NO2 Total Column Amount for 2002-03-07 (Orbit 35966)



# Search MINDS Products on GES DISC Webpage

<https://disc.gsfc.nasa.gov/>

GES DISC Search: Showing 1 - 5 [+ New Window](#)

https://disc.gsfc.nasa.gov/datasets?keywords=MINDS&page=1

COVID-19 Therape...

EARTHDATA Find a DAAC [?](#)

GES DISC Data Collections MINDS [Calendar](#) [Map](#) [Search](#)

Feedback Cloud Migration Help [Login](#) [My Dashboard](#)

Data Collections Showing 1 - 5 of 5 datasets associated with MINDS

Refine By

Dataset [Sort](#)

	Dataset	Source <a href="#">Sort</a>	Version <a href="#">Sort</a>	Time Res. <a href="#">Sort</a>	Spatial Res. <a href="#">Sort</a>	Process Level <a href="#">Sort</a>	Begin Date <a href="#">Sort</a>	End Date <a href="#">Sort</a>
<input type="checkbox"/> Atmospheric Chemistry (5)	 OMI/Aura NO <sub>2</sub> Tropospheric, Stratospheric & Total Columns MINDS Daily L3 Global Gridded 0.25 degree x 0.25 degree (OMI_MINDS_NO2d 1.1)	Aura OMI	1.1	1 day	0.25 ° x 0.25 °	3	2004-10-01	2022-11-29
<input type="checkbox"/> Atmospheric Nitric Acid (5)	 OMI/Aura NO <sub>2</sub> Tropospheric, Stratospheric & Total Columns MINDS Daily L2 Global Gridded 0.25 degree x 0.25 degree (OMI_MINDS_NO2G 1.1)	Aura OMI	1.1	1 day	0.25 ° x 0.25 °	2G	2004-10-01	2022-11-29
<input type="checkbox"/> Nitric Oxide (5)	 OMI/Aura NO <sub>2</sub> Tropospheric, Stratospheric & Total Columns MINDS 1-Orbit L2 Swath 13 km x 24 km (OMI_MINDS_NO2 1.1)	Aura OMI	1.1	98.8 minutes	13 km x 24 km	2	2004-10-01	2022-11-30
<input type="checkbox"/> Nitrogen Dioxide (5)	 GOME/ERS-2 NO <sub>2</sub> Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath 40 km x 320 Km (GOME_MINDS_NO2 1.1)	ERS-2 GOME	1.1	100 minutes	40 km x 320 km	2	1996-01-01	2003-06-22
<input type="checkbox"/> Nitrogen Oxides (5)	 TROPOMI/S5P NO <sub>2</sub> Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath 5.5 km x 3.5 km (TROPOMI_MINDS_NO2 1.1)	Sentinel-5P TROPOMI	1.1	101.5 minutes	5.5 km x 3.5 km	2	2018-05-01	2022-01-01

Subject [Sort](#)

Measurement [Sort](#)

Source [Sort](#)

Processing Level [Sort](#)

Project [Sort](#)

Temporal Resolution [Sort](#)

Spatial Resolution [Sort](#)

# TROPOMI MINDS L2 Dataset Landing Page

## Level 2 Subsetter to Collocate L2 Pixel with In-situ Surface Observation

GES DISC Dataset: TROPOMI/S5P

[https://disc.gsfc.nasa.gov/datasets/TROPOMI\\_MINDS\\_NO2\\_1.1/summary?keywords=MINDS](https://disc.gsfc.nasa.gov/datasets/TROPOMI_MINDS_NO2_1.1/summary?keywords=MINDS)

COVID-19 Therape...

EARTHDATA Find a DAAC ?

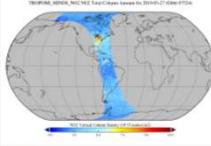
**GES DISC** Data Collections MINDS 2 Feedback Cloud Migration Help Login My Dashboard

*Atmospheric Composition, Water & Energy Cycles and Climate Variability*

Back to search results

Making Earth System Data Records for Use in Research Environments

TROPOMI/S5P NO<sub>2</sub> Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath 5.5 km x 3.5 km  
(TROPOMI\_MINDS\_NO2)

  
[View Full-size Image](#)

As part of the NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) program, this project entitled "Multi-Decadal Nitrogen Dioxide and Derived Products from Satellites (MINDS)" will develop consistent long-term global trend-quality data records spanning the last two decades, over which remarkable changes in nitrogen oxides (NOx) emissions have occurred. The objective of the project is to adapt Ozone Monitoring Instrument (OMI) operational algorithms to other satellite instruments and create consistent multi-satellite L2 and L3 nitrogen dioxide (NO<sub>2</sub>) columns and value-added L4 surface NO<sub>2</sub> concentrations and NOx emissions data products, systematically accounting for instrumental differences. The instruments include Global Ozone Monitoring Experiment (GOME, 1996-2011), SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY, 2002-2012), OMI (2004-present), GOME-2 (2007-present), and TROPOspheric Monitoring Instrument (TROPOMI, 2018-p ...more)

Data Access

Online Archive

Earthdata Search

OPENDAP

[Subset / Get Data](#)

Product Summary Data Citation Documentation Data Calendar

**Shortname:** TROPOMI\_MINDS\_NO2

**Longname:** TROPOMI/S5P NO<sub>2</sub> Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath 5.5 km x 3.5 km

**DOI:** 10.5067/MEASURES/MINDS/DATA203

**Version:** 1.1

# Subset/Get Data: A Level-2 Subsetter Use Case

## How to Subset Level-2 Data

<https://disc.gsfc.nasa.gov/v/information/howto?keywords=Level%202%20Subsetter&title=How%20to%20Subset%20Level-2%20Data>



S5P\_L2\_NO2\_HiR\_2/summary?keywords=S5P\_L2\_NO2\_HiR\_2

Download Method:  Get File Subsets using the GES DISC Subsetter

Get Original Files  
Generate unmodified file links directly from the archive.

Get File Subsets using the GES DISC Subsetter   
Generate file links supporting geo-spatial search and crop, selection of variables, selection of time of day, and data presentation, in netCDF format.

Method Options 

Refine Date Range:  2021-12-01 00:00:00 to 2021-12-31 23:59:59

Refine Region:  39.372, -76.747

Default Range

Available Range: -180, -90, 180, 90 Cursor Coordinates: 34.127, -67.324

Leaflet

Use 'Refine Region' for geo-spatial subsetting 

Variables:  1 variable(s) selected

Time of Day:

Data Presentation: CROP

VECTOR: Spatial dimensions will be reduced to a single data stream dimension.  
 CROP: Spatial dimensions will be trimmed to data.  
 FULL: Spatial dimensions will remain at original lengths.

Cloud Migration Help  My Dashboard

Data Access

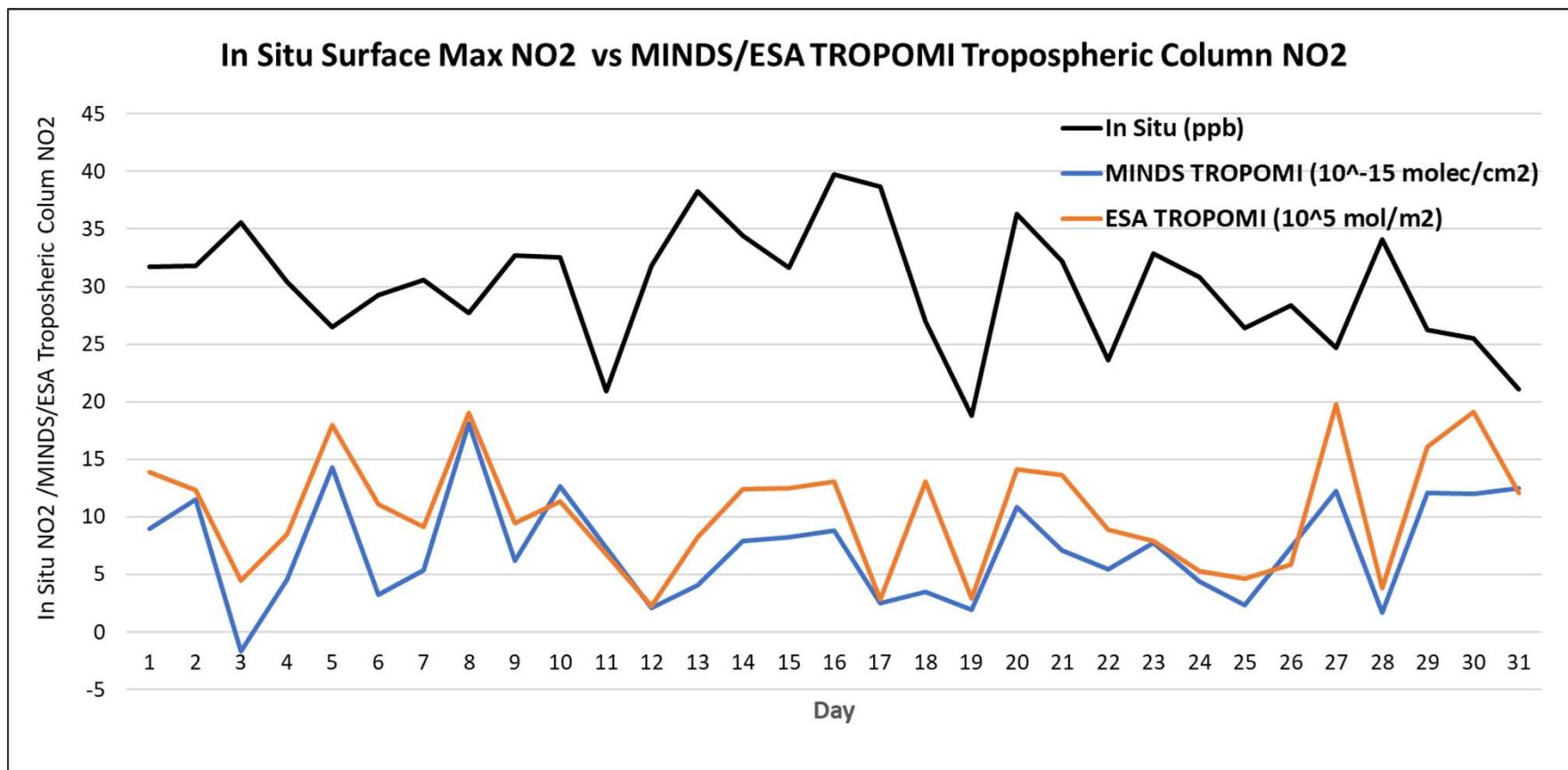
Online Archive

Earthdata Search

OPENDAP

 [Subset / Get Data](#)

# $\text{NO}_2$ Daily Change at Baltimore County, MD (EPA Site ID 24005009) in December 2021



# Giovanni - Exploring/Analyzing L3/L4 Data

## <https://giovanni.gsfc.nasa.gov/>

The screenshot shows the Giovanni Data Selection interface. At the top, there is a browser header with tabs for "Giovanni - Data Selection" and a search bar containing the URL. Below the header, the main interface has a dark blue header bar with the NASA EARTHDATA logo, a "Find a DAAC" dropdown, and links for "Feedback", "Help", and "Log out (fengding)".

The main content area is titled "GIOVANNI The Bridge Between Data and Science v 4.37". It features three main search panels:

- Select Plot:** Set to "Map, Recurring Averages".
- Select Seasonal Dates:** Set to "Enter days, months or seasons" from 2016 to 2021. A note says "Valid Range: 2004-10-01 to 2022-11-06".
- Select Region (Bounding Box or Shape):** Set to "90,20,125,50".

**Select Variables:** A sidebar on the left lists categories: Observations (selected), Disciplines, Measurements, Platform / Instrument, Spatial Resolutions, Temporal Resolutions, and Portal. Under "Observations", "NO2" is selected. The main variable list shows "Number of matching Variables: 3 of 2011" and "Total Variable(s) included in Plot: 1". The variables listed are:

Variable	Units	Source	Temp Res.	Spat.Res.	Begin Date	End Date
NO2 Total Column (30% Cloud Screened) (OMNO2d v003)	molecules/cm <sup>2</sup>	OMI	Daily	0.25 °	2004-10-01	2022-11-02
NO2 Tropospheric Column (30% Cloud Screened) (OMNO2d v003)	molecules/cm <sup>2</sup>	OMI	Daily	0.25 °	2004-10-01	2022-11-06
Upwelling longwave flux at toa (clear sky and no aerosol) (M2TMNXRAD v5.12.4)	W m-2	MERRA-2 Model	Monthly	0.5 x 0.625 °	1980-01-01	2022-09-30

At the bottom, there are links for "Responsible NASA Official: Angela Li", "Web Curator: M. Hegde", "Privacy", "Powered By ▲", "Contact Us", "Reset", "Plot Data" (highlighted in green), and "Go to Results".

# Giovanni: Recurring Averages Map

## Study COVID-19 Impact on NO<sub>2</sub> in April 2022, Eastern China

Giovanni - Data Selection x +

giovanni.gsfc.nasa.gov/giovanni/#service=QuCl&seasons=101106&starttime=2016-01-01T00:00:00Z&endtime=2021-12-31T23:59:59Z&bbox=90,20,125,50&data=OMNO2d\_003\_Colum... labeled star gear square person ⋮

COVID-19 Therape... Other bookmarks

EARTHDATA Find a DAAC ?

**GIOVANNI** The Bridge Between Data and Science v 4.37 Feedback Help Log out (fengding)

Select Plot Map, Recurring Averages i Select Seasonal Dates 04-11, 04-16 2016 to 2021 Select Region (Bounding Box or Shape) 90,20,125,50 book left arrow right arrow close

**Maps**

- Time Averaged Map
- Map, Recurring Averages**
- Time Averaged Overlay Map
- Map, Accumulated
- Animation Limited to: 365 time steps
- Map, Difference of Time Averaged

**Comparisons**

- Map, Correlation

Ocean Biology (31)  
 Oceanography (48)  
 Water and Energy Cycle (682)

► Measurements  
► Platform / Instrument  
► Spatial Resolutions  
► Temporal Resolutions  
► Wavelengths

**Select Seasonal Dates**

Scatter, Area Averaged (Static)  
Scatter (Interactive) Limited to: 30000 points  
Scatter (Static)

Scatter, Time-Averaged (Interactive) Limited to: 30000 points

**Time Series**

Time Series, Area-Averaged Differences  
Time Series, Area-Averaged  
Hovmoller, Longitude-Averaged  
Hovmoller, Latitude-Averaged

Scatter, Time Series, Recurring Averages  
Histogram  
Zonal Mean

**Miscellaneous**

Cross Section, Latitude-Pressure  
Cross Section, Longitude-Pressure  
Cross Section, Time-Pressure  
Vertical Profile

Vertical

Source Temp. Res. Spat. Res. Begin Date End Date

OMI Daily 0.25 ° 2004-10-01 2022-11-02

Responsible NASA Official: [Angela Li](#) [Privacy](#) [Powered By ▲](#) [Contact Us](#) Reset Plot Data Go to Results

# Giovanni – Select Days, Months, Seasons, Year Range

Days: 4/11–04/16 Year Range: 2006-2010, 2011-2015, 2016-2021, 2022

The screenshot shows the GIOVANNI interface with several modals open for date selection:

- Select Seasonal Dates**: Shows a date range from 04-11, 2016 to 04-16, 2021. The "Days" radio button is selected. Two calendar grids show April 2016 and April 2021. The 11th in 2016 and the 16th in 2021 are highlighted.
- Select Region (Bounding Box or Shape)**: Shows a bounding box with coordinates 90,20,125,50. It includes a map view and a zoom control.
- Season Selection Modals**: Three separate modal windows for selecting months and seasons:
  - Month Selection**: Shows radio buttons for Days, Months, and Seasons. The "Months" radio button is selected. It lists months from January to December, each with a checkbox.
  - Season Selection**: Shows radio buttons for Days, Months, and Seasons. The "Seasons" radio button is selected. It lists seasonal periods: DJF, MAM, JJA, and SON, each with a checkbox.
  - Year Selection**: Shows radio buttons for Days, Months, and Seasons. The "Months" radio button is selected. It lists years from 2001 to 2022, each with a checkbox. The year 2022 is selected.

**Left Sidebar (Select Plot)**:  
Map, Recurring Averages  
Select Variables:

- Observations**: Model (1066), Observation (709)
- Disciplines**: Aerosols (253), Atmospheric Chemistry (228), Atmospheric Dynamics (733), Cryosphere (16), Hydrology (501), Ocean Biology (31), Oceanography (48), Water and Energy Cycle (682)
- Measurements**
- Platform / Instrument**
- Spatial Resolutions**
- Temporal Resolutions**
- Wavelengths**

**Bottom Navigation**: Responsible NASA Official: Angela Li, Privacy, Powered By ▲, Contact Us, Reset, Plot Data, Go to Results

# Giovanni – Select Region (Bounding Box or Shape)

## Bounding Box: Central and Eastern China

Giovanni - Data Selection x + giovanni.gsfc.nasa.gov/giovanni/#service=QuCl&seasons=101106&starttime=2016-01-01T00:00:00Z&endtime=2021-12-31T23:59:59Z&bbox=90,20,125,50&data=OMNO2d\_003\_Colum... ☆ Other bookmark

EARTHDATA Find a DAAC ?

**GIOVANNI** The Bridge Between Data and Science v 4.37 Feedback Help Log out (fengding)

Select Plot Map, Recurring Averages i

Select Seasonal Dates 04-11, 04-16 2016 to 2021

Select Region (Bounding Box or Shape) 90,20,125,50 Reset Back Forward X

Select Variables

**Observations**

Model (1066)  Observation (709)

**Disciplines**

Aerosols (253)  Atmospheric Chemistry (228)  Atmospheric Dynamics (733)  Cryosphere (16)  Hydrology (501)  Ocean Biology (31)  Oceanography (48)  Water and Energy Cycle (682)

**Measurements**

**Platform / Instrument**

**Spatial Resolutions**

**Temporal Resolutions**

**Wavelengths**

Number of 1 Keyword Var NO

Valid Period: 2001-10-01 to 2020-11-01  
Select a Shape...

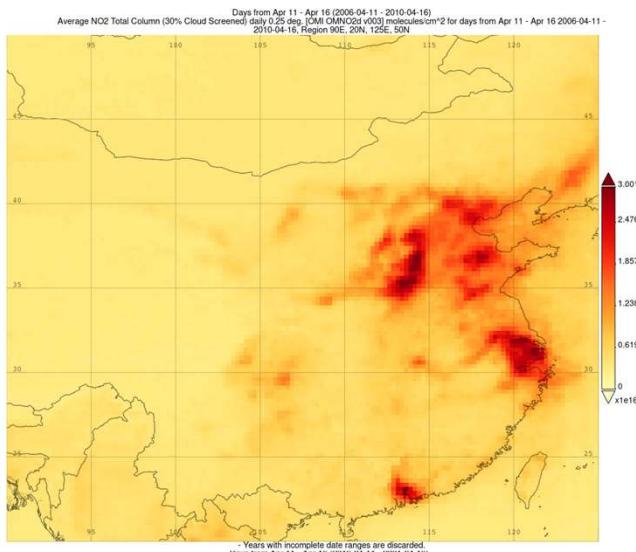
- Countries and Areas (source: [US State Department](#))
- Lakes and Reservoirs (source: [World Wildlife Fund](#))
- Land Only file (source: [GES DISC](#))
- Sea Only file (source: [GES DISC](#))
- US States (source: [TIGER/Line, US Census Bureau](#))
- Watersheds (source: [Major Hydrological Basins, FAO \(United Nations\)](#))
- World\_Regions (source: [ESRI](#))

Select a Shape...

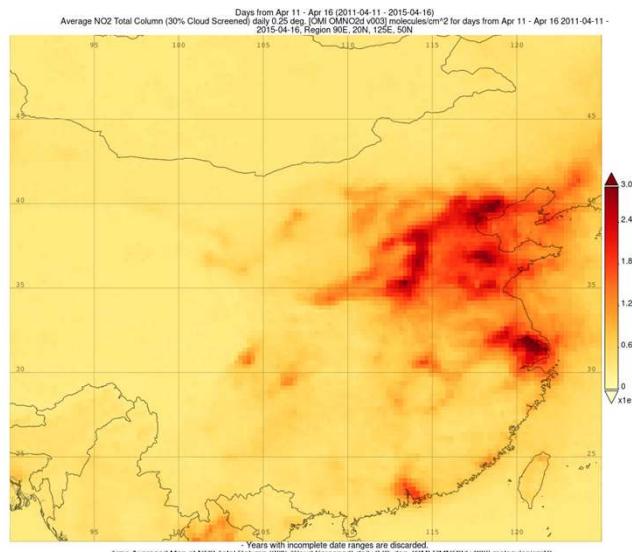
21°53'N, 79°06'E  
40°00'N  
20°00'N  
80°00'E 100°00'E 120°00'E 140°00'E

Responsible NASA Official: [Angela Li](#) [Web Curator: M. Hegde](#) Privacy Powered By ▲ Contact Us Reset Plot Data Go to Results

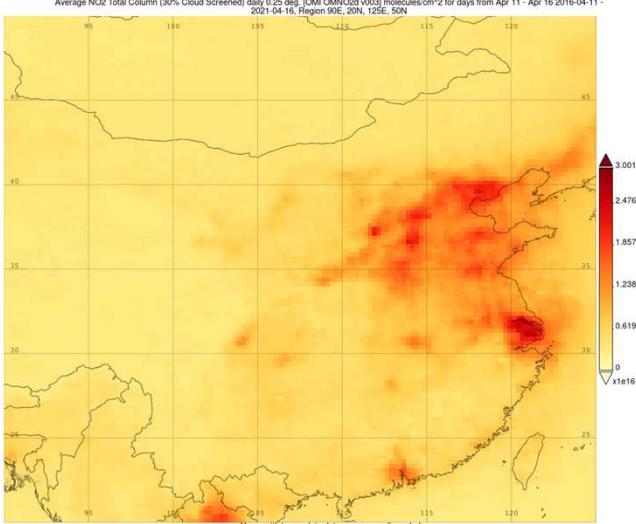
# Six-Day (4/11 – 4/16) NO<sub>2</sub> Average



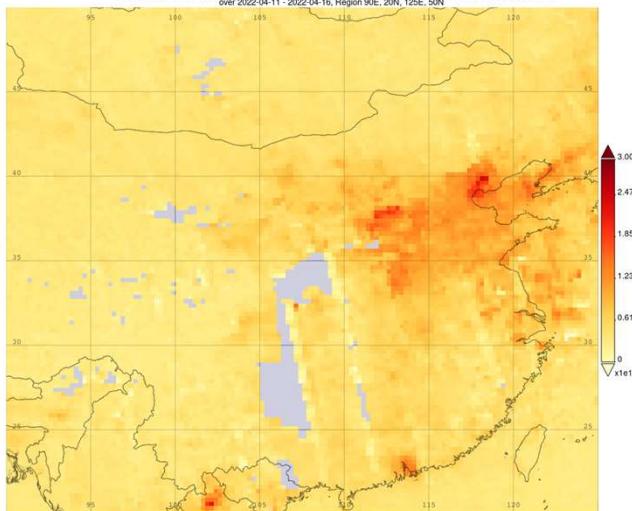
2006  
-  
2010



2011  
-  
2015



2016  
-  
2021



2022

# GES DISC Data Migration to Cloud

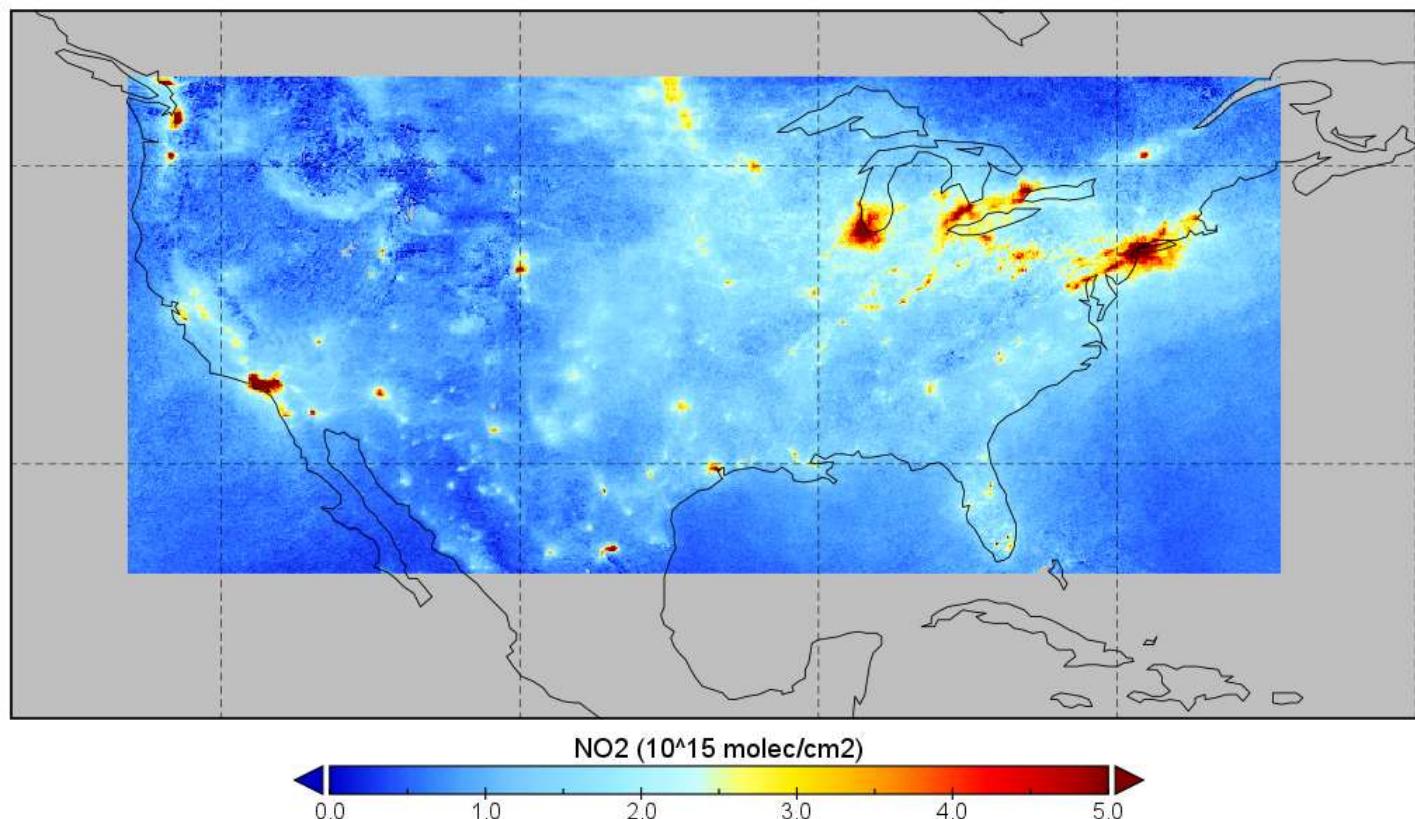
- Data migration to cloud is ongoing and updates are posted on the GES DISC Cloud Migration Page:  
<https://disc.gsfc.nasa.gov/information/documents?title=Migrating%20to%20the%20Cloud>
- All of GES DISC's traditional services and download methods are still available
- Free data download will continue and won't change, i.e., a user only pays cloud computing service but not NASA data
- In-cloud AWS direct S3 access is available
  - No need to download the data for research and application

One example: generating user-defined Level 3/Level 4 products by directly accessing Level 2 data without downloading



# User-defined L3 TROPOMI Gridded Monthly NO<sub>2</sub> with QC over CONUS from NASA HAQAST (Health and Air Quality Application Science Team)

May 2018 Monthly NO<sub>2</sub>



# Summary

- In addition to many already distributed products (OMI, TROPOMI, MERRA-2), GES DISC released new products from MINDS project for air quality research and application communities
- Level 2 Subsetter and Giovanni are valuable tools to download, explore, and analyze data
- GES DISC data migration to cloud is ongoing and will add more convenient ways to access data
- User feedback is very welcome:  
<https://disc.gsfc.nasa.gov>    [gsfc-dl-help-disc@mail.nasa.gov](mailto:gsfc-dl-help-disc@mail.nasa.gov)

